Blue−Laser MOVPE Structures Grown on Bulk GaN Crystals

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The single crystals of GaN grown at high hydrostatic pressures (about 15 kbar) and high temperatures (about 1800K) possess a very low dislocation density (below 10^3 cm^{-2}) and sizes of about 100 mm^2 . These crystals are used as substrates for MOVPE growth of laser structures.

The most important question we had to answer was if the ternary compounds InGaN and AlGaN layers on GaN would be strained or relaxed by misfit dislocations. To answer this question we grew a series of these ternary layers of various compositions and thickness and examined them using high−resolution X−ray diffraction sensitive to dislocation density larger then 10^4 cm−2. These experimental results indicated that the laser structure grown on bulk GaN crystal should be fully strained (without mismatch dislocations).

The further research confirmed this prediction. Atomic force microscopy (AFM) scans do not show any threading dislocations. The perfect atomic steps are not disturbed by the presence of dislocations and indicate a step−flow growth mode on a slightly misoriented substrate.

However, significant deviation from perfect epitaxial structure could be observed by diffuse scattering of X−ray diffraction around InGaN peaks (both, thick layers and quantum wells) what meant a certain indium segregation or variation of well/barrier thickness. Even more important problem for fully strained epitaxial layers on relatively thin GaN substrates is the sample bowing. In extreme cases, for very thick AlGaN claddings, the bowing radius is too small, what makes laser device processing difficult. Therefore, thickness of the substrate, claddings layers (tensile strain) and InGaN layers (compressive strain) must be well optimized with respect to bowing and device performance simultaneously.

The structures were then used for constructing blue lasers stimulated either by optical and electrical pumping. For the optical pumping, we achieved a lasing threshold of about 2.5 kW/cm^2 , whereas for electrical pumping, about 5 kA/cm^2 , pulsed mode. The wavelengths of the LDs could be changed from 390 nm to 435 nm by varying the growth conditions.

1. Introduction

III−N semiconductors have attracted big attention in recent few years what resulted in realization of violet laser diodes (LDs) [1] and their commercialization. However, high dislocation density in heteroepitaxial structures of order $>10^6$ cm^{-2} is an obstacle hard to overcome in realization of high power lasers and other devices with large area. Here we describe some properties of epitaxial layers and structures grown on bulk GaN crystals with a low dislocation density below 10^3 cm^{-2} [2]. This application of low dislocation substrates leads to new possibilities in design of high power, large area LD devices.

2. Experimental and Discussion

The films were grown by MOVPE method in vertical home−made low pressure reactor. The substrates were mechanically polished to a thickness of 60μm. Epi side Ga−face (0001) was reactive ion etched (RIE) prior to the growth. We grew a series of AlGaN and InGaN ternary layers of various compositions and thickness'. High−resolution X−ray diffraction results indicated that the laser structure grown on bulk GaN crystal should be fully strained (without mismatch dislocations) [3]. For fully strained layers we have observed large bowing due to the relatively small substrate thickness and big lattice mismatch. In Figure 1 is an example of 1μm thick Al0.1Ga0.9N layer with a bowing radius of 6.5cm, what is typical total claddings thickness and composition of our laser structures. Some strain engineering approach, including short period superlattices (SL), compliance layers, and careful optimalization of substrate thickness seems to be unavoidable in that case.

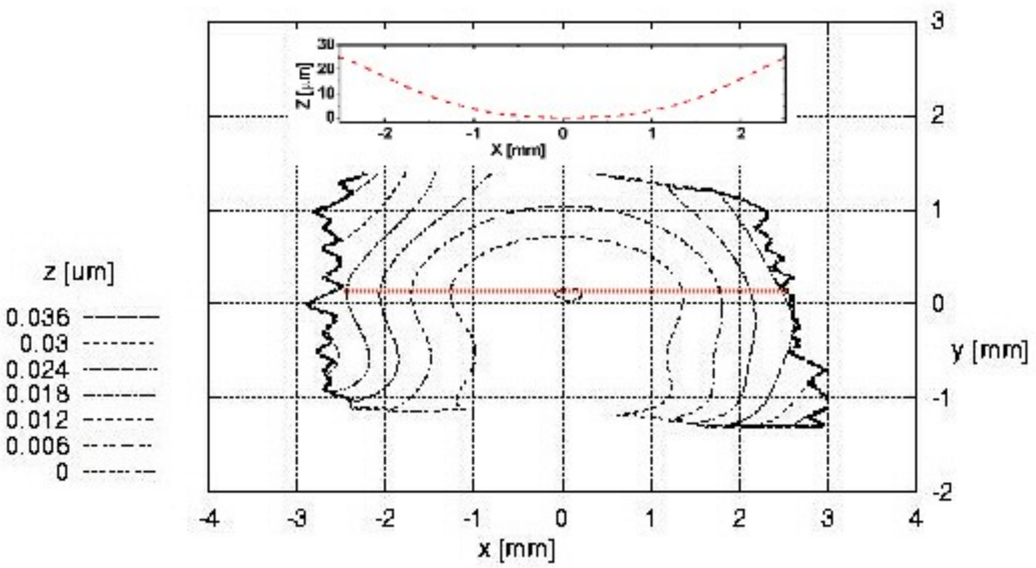

Fig.1 Surface curvature of 1µm thick $Al_{0.1}$ $Ga_{0.9}$ N layer on 60µm bulk GaN substrate.

Figure 2 shows XRD curve for multiple quantum well (MQW) structure (10xInGaN/InGaN:Si) on bulk GaN substrate, similar to used in our LDs. One should mention, that diffractogram possess slightly broadened satellites peaks what is probably related to In−segregation or variation of well/barrier thickness. Both mechanisms are not excluded using AFM on thick InGaN layers and MQW samples grown on bulk GaN crystals. The origin of satellite broadening has to be further investigated.

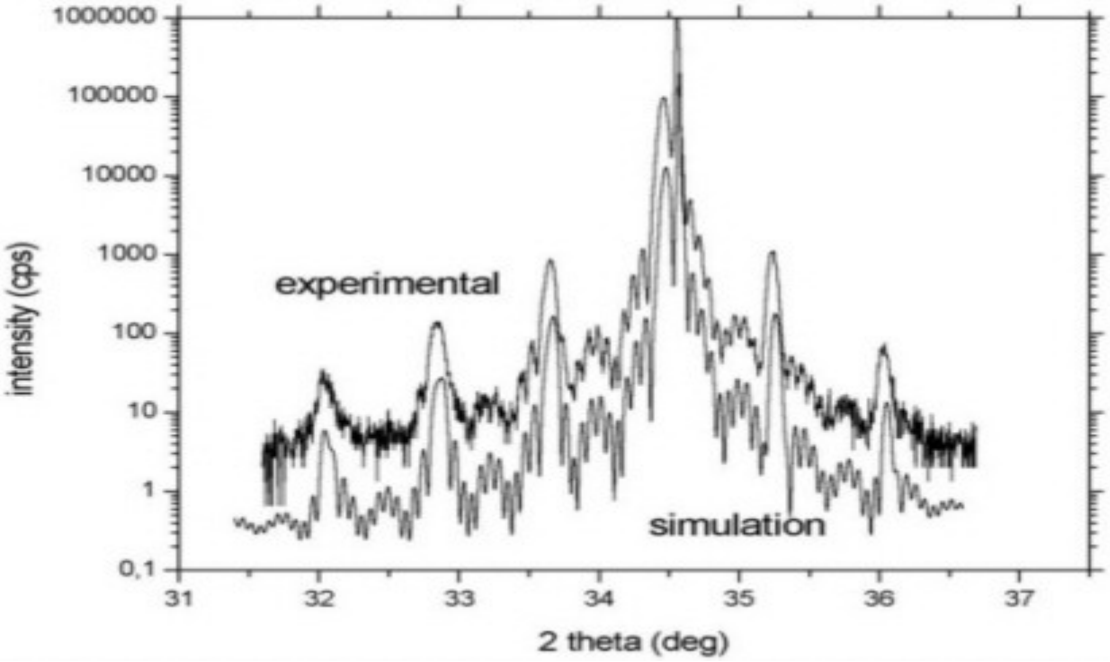

Fig.2 Experimental and simulated XRD curve for InGaN/InGaN 10MQW structure on bulk GaN substrate.

Our laser epitaxial structures have MQW active region, typically 5 quantum wells of $In_{0.1}$ $Ga_{0.9}$ N/$In_{0.02}$ $Ga_{0.98}$ N:Si 35−40Å/60−85Å, followed by 200Å thick $Al_{0.28}$ $Ga_{0.72}$ N:Mg electron blocking layer. A 1000−1400Å thick n−type and 700−1200Å thick p−type GaN layers surrounding active region acts as waveguide core. As n−claddings we use typically 0.6µm thick GaN:Si/$Al_{0.18}$ $Ga_{0.82}$ N:Si, 25Å/25Å superlattice, whereas p−type claddings are 0.35µm thick bulk $Al_{0.09}$ $Ga_{0.91}$ N:Mg or GaN:Mg/$Al_{0.18}$ $Ga_{0.82}$ N:Mg, 25Å/25Å superlattice. A 300Å thick p−type GaN layers acts as contact layers. The stripe−geometry LDs are 3−20µm wide and 500µm long with cleaved mirrors. On both mirrors, we use 50% reflection coatings consisted of two pairs of quarter wave SiO_X /ZrO_2 dielectric layers. Ti/Au back and Ni/Au−based front−side n− and p−type metallization is used. LD devices are p−type up mounted on a copper base.

The structures were stimulated either by optical and electrical pumping. For the optical pumping (no Mg doping), we achieved very low lasing threshold of about 2.5 kW/cm^2 [4], whereas for electrical pumping, lasing threshold was about 5 kA/cm^2 , pulsed mode. Best threshold currents were 84mA for 3x500µm stripes and 400mA for 15µm stripes (@8−15V). The pulsed output power per facet of wide stripe devices exceeded 0.5W at 405nm (Fig.3).

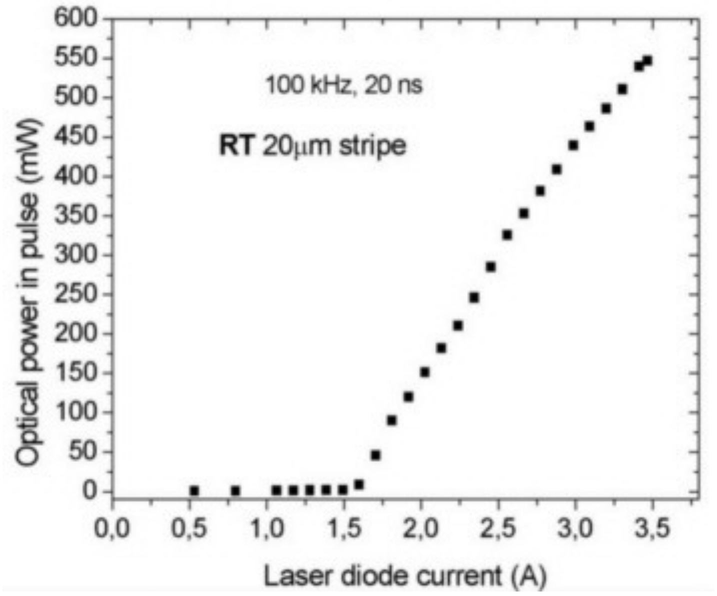

Fig.3 Output power (L−I curve) of 405nm laser device in pulsed mode.

3. Conclusions

Pressure grown bulk GaN crystals are successfully used as substrates for violet LDs and allow us to construct high power devices. At present some issues related to device mounting/packaging and processing has to be solved in path toward commercialization of these devices. Particularly substrate thickness must be well optimized with respect to bowing and performance of very strong strained devices.

Acknowledgments

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